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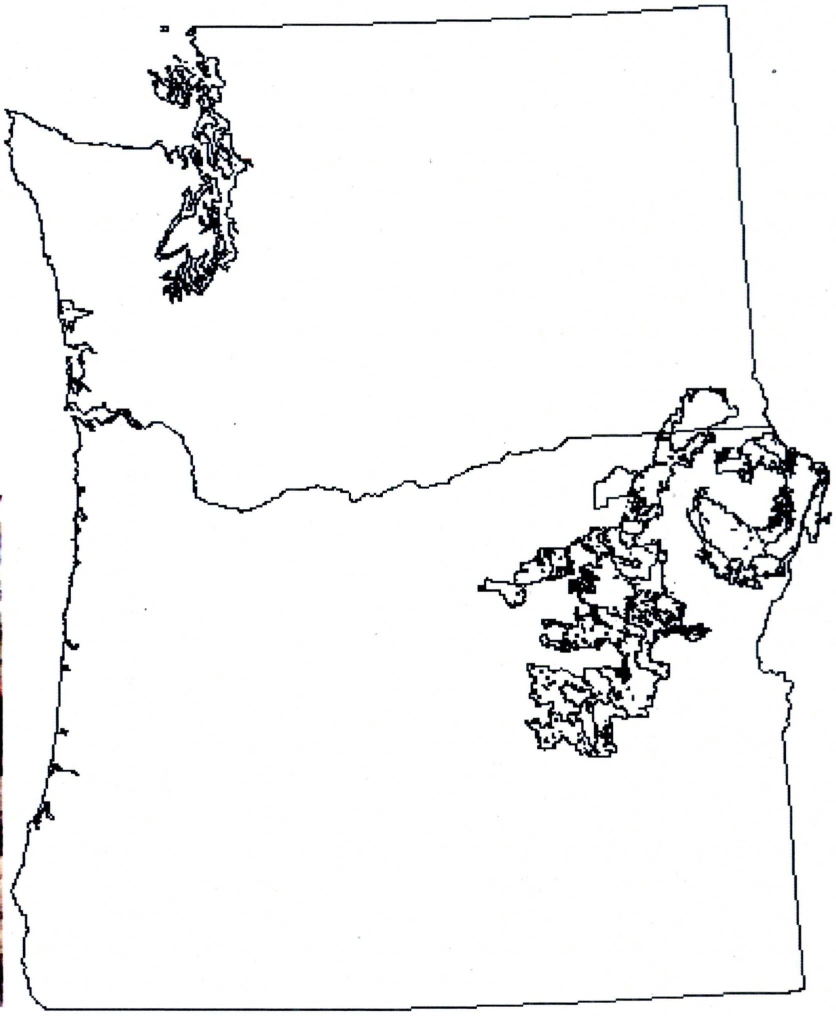
Review of the Prescribed Fire Program on Emigrant Creek Ranger District - 2001

Donald W. Scott



Caring for the Land and Serving People

Review of the Prescribed Fire Program on Emigrant Creek Ranger District – 2001

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Introduction

Spring burning offers an early-season window of opportunity to accomplish several important management and ecosystem restoration objectives: achieve forest fuels reduction, reduce the potential for stand-replacing wildfire, improve domestic and big-game wildlife forage conditions, modify habitat to reduce potential outbreaks of deleterious insects, and to begin reintroducing fire back into those ecosystems that developed in the environment of frequent, low-intensity surface fire under the natural fire regime. Nearly all ranger districts in the Blue Mountains conduct some level of spring burning each year. In the past, nearly all planned burning occurred in the fall after rains recharged moisture in fuels that had dried out through the hot summer season. Fall burning is still conducted during the safe burn window at the end of the season up until snowfall. However, burning in the spring to meet various resource management objectives and reduce fuels is now practiced with nearly the same regularity as burning in the fall.

It is well known that agency fire suppression and prevention policies have prevented natural fire events from occurring for many decades throughout the west. As a result of the vegetation changes wrought by fire exclusion and past harvesting and grazing practices, development of stands have led to overstocking with sometimes dramatic changes in species composition and structure, as well as alteration of various natural ecological processes. Landscape changes have occurred to such a degree in the Blue Mountains that some areas are now frequently characterized by wildland fire events, insect outbreaks, and other ecosystem disturbances occurring outside of pre-EuroAmerican settlement historic patterns, or the Historic Range of Variability (HRV) (Scott 1996).

Springtime burning within any given year broadens the opportunity to utilize controlled fire to achieve planned management objectives, however, in some cases, ecological benefits derived from underburning may be tempered by certain unintended results that may not be apparent until several years later. It is well to remember that springtime burning is not the natural timing of historic burn occurrence, and there may be untoward results unless the timing of such activities are accompanied by careful preparation, planning, and implementation so that injuries to the roots, bole, and crown of desirable tree species to be retained on the site are minimized. Even though spring burning has increased in use since the early 1970s, there are opportunities for improvement in conducting spring underburning; and there is still much to learn about the process and implications of this activity. Research and monitoring efforts now underway for both prescribed underburns and wildfires continue to generate new and useful information, but to gain wider benefit and understanding, investigations must be expanded, refined, and carried out over broader areas of differing environments and plant communities. Incorporation of any new information is best accomplished within an adaptive management environment where adjustments in procedures and refinements of techniques can be made with the emergence of new information and improvements in technology.

In the remainder of this report, I would like to share my observations on the prescribed burns that I visited on the Emigrant Creek Ranger District on August 28-30, 2001, and also provide a general discussion, along with some recommendations for improving survival of desirable stand components during underburning, and for minimizing future insect infestations that could seriously compromise intended, desirable results.

Observations

Joaquin Underburn (Unit 25)

The first area visited was that portion of the Joaquin Underburn that was burned in spring (in early May) 2001, lying adjacent to Highway 395. The area burned is about 254 acres. Ground ignition sources used to ignite the unit included ATV with drip torch and some hand lighting with drip torch.

Surface fuels prior to burning consisted mostly of needle litter and grass, with very little slash from earlier thinning entries. The area had been commercially thinned in the late 1980s or early 1990s by whole tree yarding methods. Most slash generated from these entries had been piled and burned, while some debris was chipped and hauled off site. The stand is now composed of second-growth ponderosa pine sawlogs and scattered large-diameter old-growth timber (some over 36-inches dbh) that is well over 200 years in age. The 1000-hour fuel moisture conditions just prior to ignition were 10 percent. About a month after burning, the area received precipitation from a snowstorm that occurred on June 11 and 12.

The prescription for the Joaquin Underburn called for 2-foot flamelengths, but throughout most of the area visited bole scorch indicated that flamelengths were probably higher. Also, the bottom 1/4 to 1/3 of the live crowns of most trees had been scorched by convection heat from combustion of surface fuels. In a few cases, the fire burned with greater intensity, scorching nearly the entire length of the live crown of trees.

Duff around most of the trees had been completely consumed exposing the mineral soil. When we checked for live cambium on the roots and root collar of the smaller diameter trees we found live cambium in virtually every case except where heavier fuels had burned up against the bole of the tree, or where such fuels had been in close proximity to the boles of the tree. The size of these heavy surface fuels allowed them to burn with sufficient heat intensity and duration to either conduct heat downward through the upper soil horizons and kill roots growing relatively close to the soil surface, or radiate enough heat to the bark on the lower bole to kill the cambium in that part of the tree.

We noted numerous cases in which the cambium on the roots, or at the root collar of larger, mature trees (24-inches dbh and larger) was dead wherever the pre-burn duff depth was great, and had been 100-percent consumed (fig. 1). Typically, those trees also had been attacked by red turpentine beetles, *Dendroctonus valens.* Since these bark beetles require live cambium in which to produce their brood, they were good indicators of locations on the bole where cambium survived the fire, only to be later killed in patches by the broods of this insect. These locations of beetle attack add to the already sometimes significant areas of cambium killed by heat from the fire, and will likely create enough additional stress on these trees to draw in other bark beetles such as western pine beetle (*D. brevicomis*), mountain pine beetle (*D. ponderosae*), pine engravers (*Ips pini*), the emarginate Ips (*I. emarginatus*), or metallic woodborers mostly of the genus *Melanophila*: insect species which account for the majority of post-fire (immediate and delayed) insect-caused tree mortality in fire-injured ponderosa pines in the Blue Mountains. You can expect to see some of these injured trees die from future attacks by bark beetles and woodborers over the next 3 or 4 years based on our monitoring and observations elsewhere.

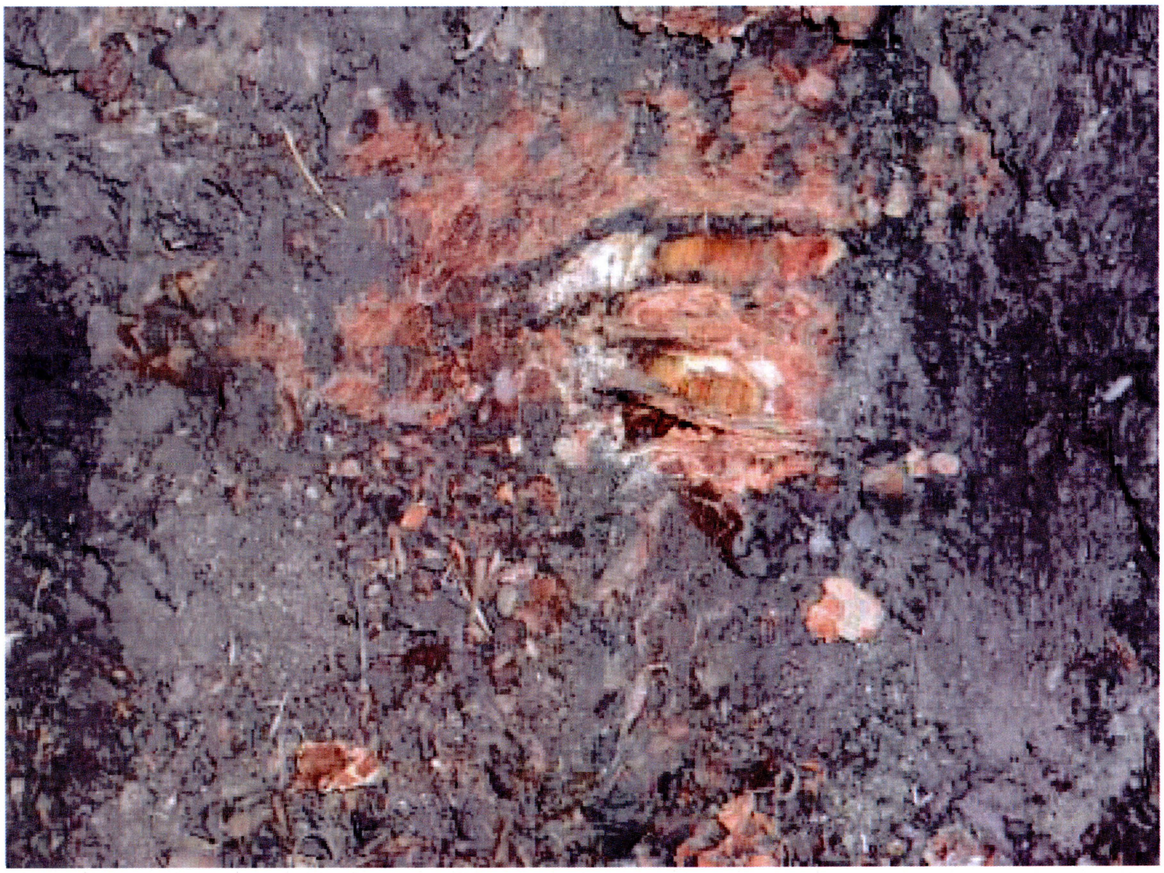


Figure 1. Dead cambium (associated with darker, resin-soaked sapwood areas) at base of old-growth ponderosa pine on the Joaquin Underburn, Emigrant Creek Ranger District. (photo by D. W. Scott, August 28, 2001).

In addition, it is unfortunate this unit to happens to lie within several active centers of blackstain root disease caused by the fungus *Leptographium wageneri.* This disease has infected several trees in each center, and they have become very attractive to bark beetles. For the most part the tree mortality in each center has resulted from the combined actions of insects and disease. Several of these centers of tree mortality are scattered in stands along both sides of Highway 395, and have been known to the district for years. We confirmed the root disease presence by examining the sapwood of roots of a couple of smaller symptomatic trees in this burn unit. Fire injury adds more stress to root disease-infected trees increasing their attractiveness to insects and the probability of drawing additional populations of tree-killing bark beetles into these stands. The multiplication of populations of cambial-feeding insects in these stands increases local beetle pressure which in turn increases the likelihood of killing not only disease infected trees, but some of the otherwise healthy, fire-injured larger trees in the future.

Silvies South Prescribed Fire (Unit B)

The Silvies South Prescribed Fire is composed of two units. Unit A is approximately 2,000 acres in size and was burned in the spring of 1997. Unit B is approximately 1,000 acres in size and it was burned in the spring of 1999. Both areas are within the Curry Timber Sale, which was an improvement cut targeting smaller trees within the sale area.

The Unit B underburn was completed utilizing a helicopter equipped with an Aerial Ignition Device dispensing ping-pong balls treated with chemicals that react and ignite combustible surface fuels and vegetation upon impact. Most of the area appeared to have received only a light burn except for where the fire burned longer in heavier fuels. According to district fire personnel, this latter condition lasted for 2 to 2 ½ weeks before mop-up was completed. We observed one area of about 5 acres that was located on a rocky knoll where the fire took off and burned with high intensity, killing several trees at this site. Although 1999 was a wetter year starting out, according to the district fire personnel, fuel components dried out relatively soon after snow melt. The moist conditions to begin with, at the time of ignition, may have accounted for the relatively light burn on this unit.

Insect activity in this unit was minimal. We noted only one 18-inch dbh ponderosa pine that had been attacked and killed by western pine beetle in 2000. The only other insect-caused tree mortality we noted was caused by flatheaded woodborers that had killed 2 or 3 trees in one location of the unit we walked through (fig. 2). The red turpentine beetle was colonizing the bases of several fire-scorched trees throughout the unit, but these were not expected to cause tree mortality. No further insect damage was noted in this unit. The risk of future infestations by bark beetles in this unit appears to be low owing to the relatively light burn, and light fire injury to trees. Contrasting this area with the Joaquin Underburn, there appeared to be much less severe injury to bole and root cambium than we observed at Joaquin. We did see some large diameter pines with considerable mortality of cambium at the base of trees, but so far these trees are still alive, with a couple of exceptions. It would be prudent to monitor survivorship of these larger trees in this unit over the next several years.

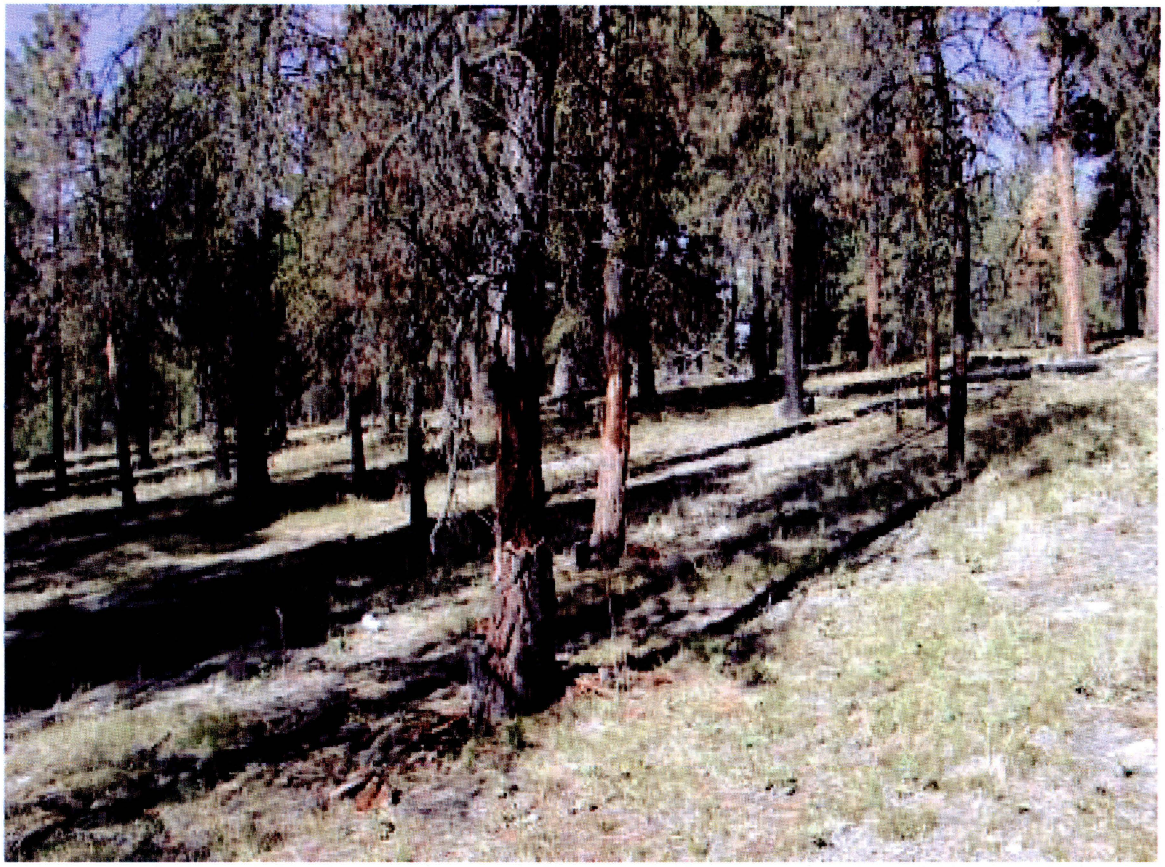


Figure 2. Scattered second-growth ponderosa pines killed by flatheaded woodborers on the Silvies South Underburn, Emigrant Creek Ranger District (photo by D. W. Scott, August 28, 2002).

Silvies South Prescribed Fire (Unit A)

Except for a small portion of the unit that has residual old-growth pines in excess of 200 years of age, this unit, like the last, really doesn't have an old overstory pine component like that present on the Joaquin Underburn. Most of the unit is second-growth pine. Consequently, we saw little tree mortality since these second-growth pines have a relatively shallow duff accumulation, and are not as prone to root injury from underburning. The residence time of smoldering combustion and heating of root systems is shorter under these trees than in large pines with deep duff accumulation.

Insect activity is minimal, as would be expected where burn intensity is light, and injuries to bole, crown, or roots are also light. Most of the time we found that the large trees had healthy cambium. Even attacks by turpentine beetle were hard to find on fire-scorched trees. Hence, risk of future insect activity in this unit appears to be low overall.

I noted that the stands in this unit are overstocked and many of the smaller trees had been marked with blue paint for thinning. There is benefit in initially reducing some of the fuel level by underburning prior to thinning in situations where fuel conditions would be excessive and present a greater hazard to underburning, if stands were thinned first. A future underburn will be needed to reduce new activity fuels created by thinning, assuming a thinning operation will take place some time in the near future.

We noted on the eastern side of the unit that the fire made a little run up the hill, and all along the ridgetop, and killed a small patch of timber over perhaps 2 or 3 acres. There were no apparent insect attacks on these trees as most were already dead from fire. However, surviving trees along the periphery that might have been scorched by fire and still have areas of live cambium on the bole could have been attacked by woodborers. We did not take the time to check these trees to determine if that were true. Evidence from wildfires suggests these beetles opportunistically attack fire-injured hosts for a period of time after the fire. We frequently have found that especially the large pole- and small sawlog-size fire-injured pines in wildfires are ultimately killed by woodborers over a 2- or 3-year period after the fire. The relative risk of attack to the residual, uninjured healthy trees is usually low, as these woodboring insects seem to prefer attacking the most weakened of the trees injured by fire, and are normally not very aggressive.

In another area of the unit we observed a ¼-acre patch of smaller dead second-growth pine, many of which were on the ground and had been attacked by woodborers and pine engraver beetles in earlier years, before the fire. We also noted evidence of mountain pine beetle attack (pitch masses and beetle galleries) in some of these trees. I suspect that this mortality could be attributed to overstocking and drought stress during earlier years.

Black Rock Natural Fuels Reduction Project

The Black Rock Natural Fuels Reduction Project is located approximately 17 air miles northwest of Burns, Oregon. It occupies an area of approximately 7,000 acres. About 800 acres of the total area are in BLM blocks and the rest are Forest Service. The project objectives are to reduce the potential for stand replacing fire, reintroduce fire to the ecosystem and to increase forage for wildlife and domestic livestock use. Stands are composed of mostly second-growth ponderosa pine overstory with occasional large residual trees left from logging during the first half of the Twentieth Century. Some areas have mixed conifer stocking that includes ponderosa pine, Douglas-fir, white fir, and juniper. Pine and juniper reproduction occurs in some openings. Understory cover vegetation includes grasses, sagebrush, bitter brush, and current.

This prescribed fire was ignited using a combination of aerial ignition (a helicopter using ping-pong ball aerial ignition technology) in part of the area, and hand lighting with drip torch and ATV ignition in the remainder. The 1000-hour fuel moisture content was at 14% when ignited. The fire prescription called for 2 to 4 foot flame-lengths producing at least 60% mortality in the seedling and sapling trees. The prescription intended to retain 90% of the overstory trees greater than 18 inches dbh. To meet resource objectives, the fire behavior was expected to produce a low to medium intensity burn with some occasional torching of individual or groups of trees.

To get an overview of this large project area, we drove through portions of the burn and stopped and walked through stands to see the burn from close up. The first area we looked at was a BLM block along Forest Road 2840. This area was hand lit in 1999 and achieved a very light burn (fig. 3). Fuel reduction on this unit appeared to be almost negligible, though admittedly we only saw a very small portion of the unit. I did not see any insect activity nor fire injury to trees of any significance in this unit.

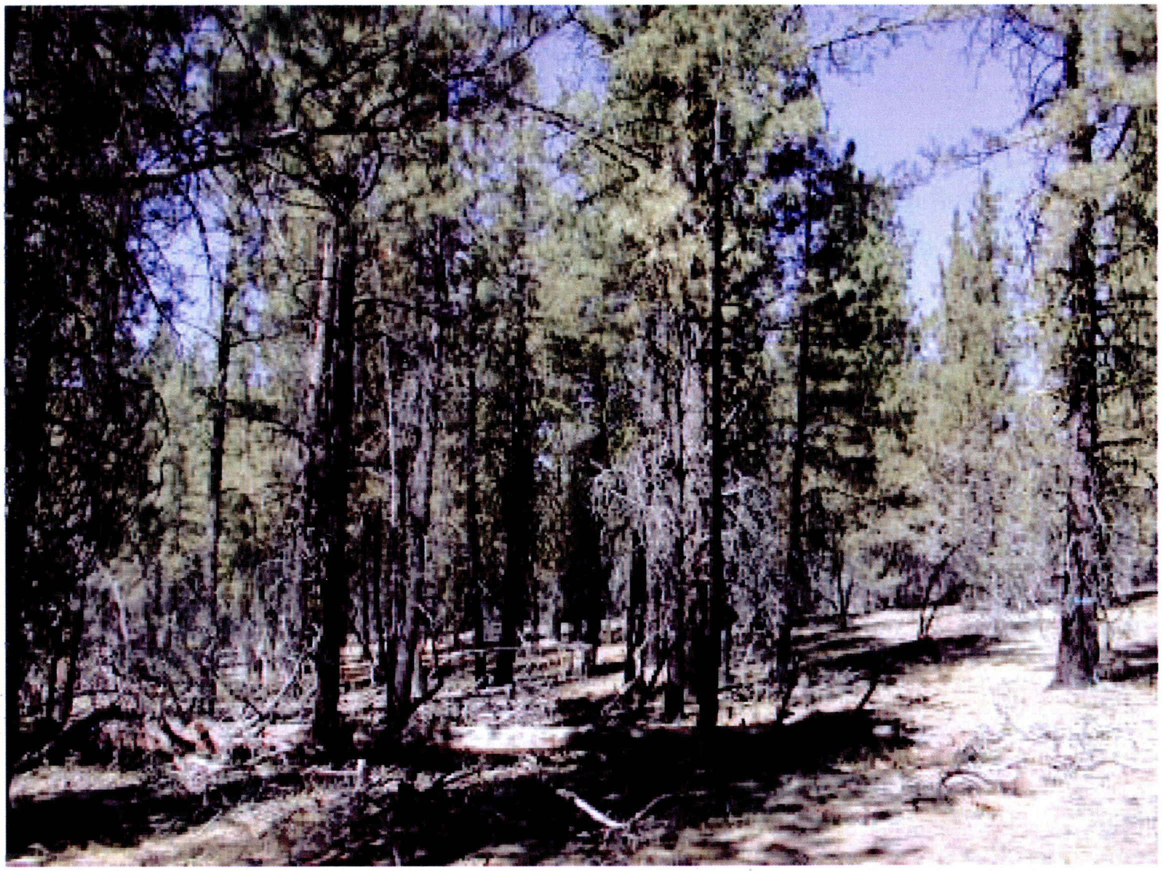


Figure 3. Light underburn on BLM block within the Blackrock Natural Fuels Reduction Project conducted cooperatively with the Emigrant Creek Ranger District (photo by D. W. Scott, August 29, 2001).

The next area we looked at was an area ignited by helicopter in 1999 at Jackknife Flat. A portion of this area contained a young ponderosa pine stand next to a small meadow. This part of the unit was hand ignited to assure better control of the burn intensity through the young pine. The only damage I saw was minor tree mortality on the edges of the stand. Overall, the burn in this portion of the project area looked good. I saw no insect activity here, and risk of future insect infestation will likely be minimal.

We next drove to a portion of unit B that is located along the 948 spur road off Forest Road 2840. This unit was also burned in 1999. We observed that the top of the ridge got a little hot during the burn, resulting in some tree mortality. In addition, we noted that mountain pine beetle, pine engravers, and woodborers have killed a number of trees in small pockets that were severely injured by fire along the ridgeline. This mortality was still on going with a few more trees under attack by beetles at the time of our visit in 2001. The tree killing was limited to trees in the 6- to 8-inch dbh classes. Larger diameter trees in this portion of the unit have not been attacked, so far. The beetle populations appeared to be on the wane, so I don't expect much additional mortality to occur over the next year or two. Trees with fire-scorched crowns along the ridge-top had produced new needles in 2001, and most of the scorched needles have already been shed, so the damage to some of these trees was being effectively masked by the time of our visit. These trees look quite healthy at the time of our visit.

At one location along the ridge-top, we found a rocky spot where fire had killed perhaps half a dozen trees. A few surviving large-diameter trees at this site had experienced severe damage to about half the supporting roots, and were under attack by several bark beetle species. These trees may survive a year or two, but will eventually become future snags. Some of the southerly aspects seemed to burn hotter resulting in a few scattered pockets of tree mortality, and creating a mosaic pattern of fire-thinned trees on these sites. Overall, this looks quite natural and pleasing from a visual standpoint, and tree mortality from the fire appears to be within the range of expected mortality given the conditions on these sites. I would suggest that one might expect to have seen similar burn patches and patterns under natural historic fire regimes.

Next, we visited unit A-3, which is an area of about 105 acres adjacent to a BLM block. The stands we visited were predominately second-growth ponderosa pine with minor amounts of a Douglas-fir component. This unit was burned in early May of 2001, just 2 or 3 days after the Joaquin Underburn. Unit A-3 was ignited by ATV equipped with drip torch, and some hand lighting with drip-torch in the steeper areas. This unit is in more of the northeast to north aspects. The north side of this unit burnt better in the more open pine areas than in the denser, mixed stands according to the fire personnel on the burn.

Several old-growth ponderosa pines are located in some of these stands. The duff depth around trees appeared to be in the order of 4 to 6 inches deep (fig. 4). Duff around several of these trees was 100% consumed within an area of one-quarter to one-third of the trees circumference. In some trees it was common to find dead cambium in the areas where 100% duff consumption occurred, whereas in other trees the dead cambium occurred only in small patches. One large tree had bole scorch up to 12 or 15 feet, and quite a few red turpentine beetles were attacking around a partially burned out area on the bole of this tree (fig. 5). On this particular tree I found only small amounts of dead cambium, although 100% of the duff was consumed around half the tree's circumference.

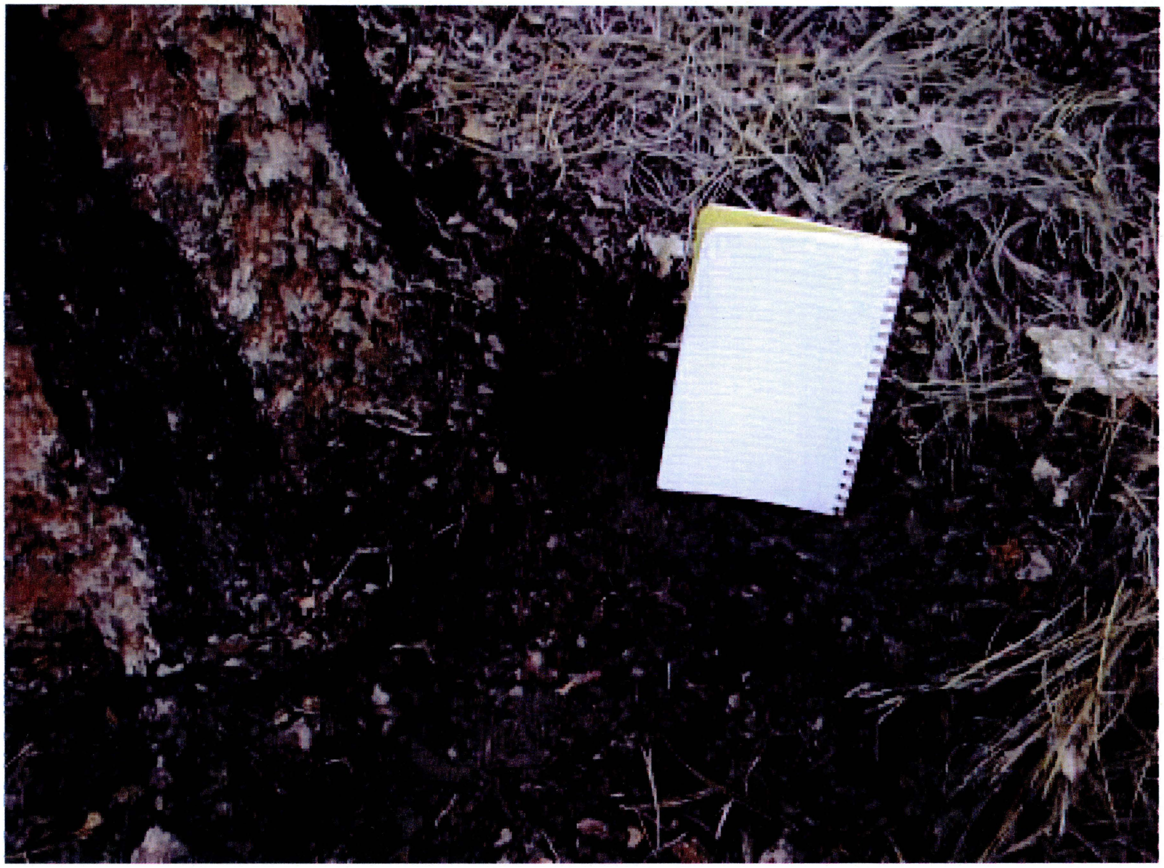


Figure 4. Depth of duff around old-growth ponderosa pines ranged between 4 and 6 inches on the Blackrock Natural Fuels Reduction Project, Emigrant Creek Ranger District (photo by D. W. Scott, August 29, 2001).

Hydrophobic soil conditions may occur when heat is applied to soil over a long duration. The condition sometimes occurs around the large-diameter trees during the smoldering or glowing combustion of the deep layer of duff. For example, on a somewhat wetter site within this unit we checked the mineral soil that was exposed around 60 to 70% of the circumference of one old-growth tree and found that the soil was hydrophobic to a depth of ½ in. I noted only patches of dead cambium around the root crown of this tree, and no turpentine beetles or other bark beetles were present at the time of this visit. Ignition conditions on this unit were probably similar to the Joaquin Underburn, however, duff and soil moisture content on this site were likely higher given that cambium damage in most cases did not appear to be as severe on this unit.

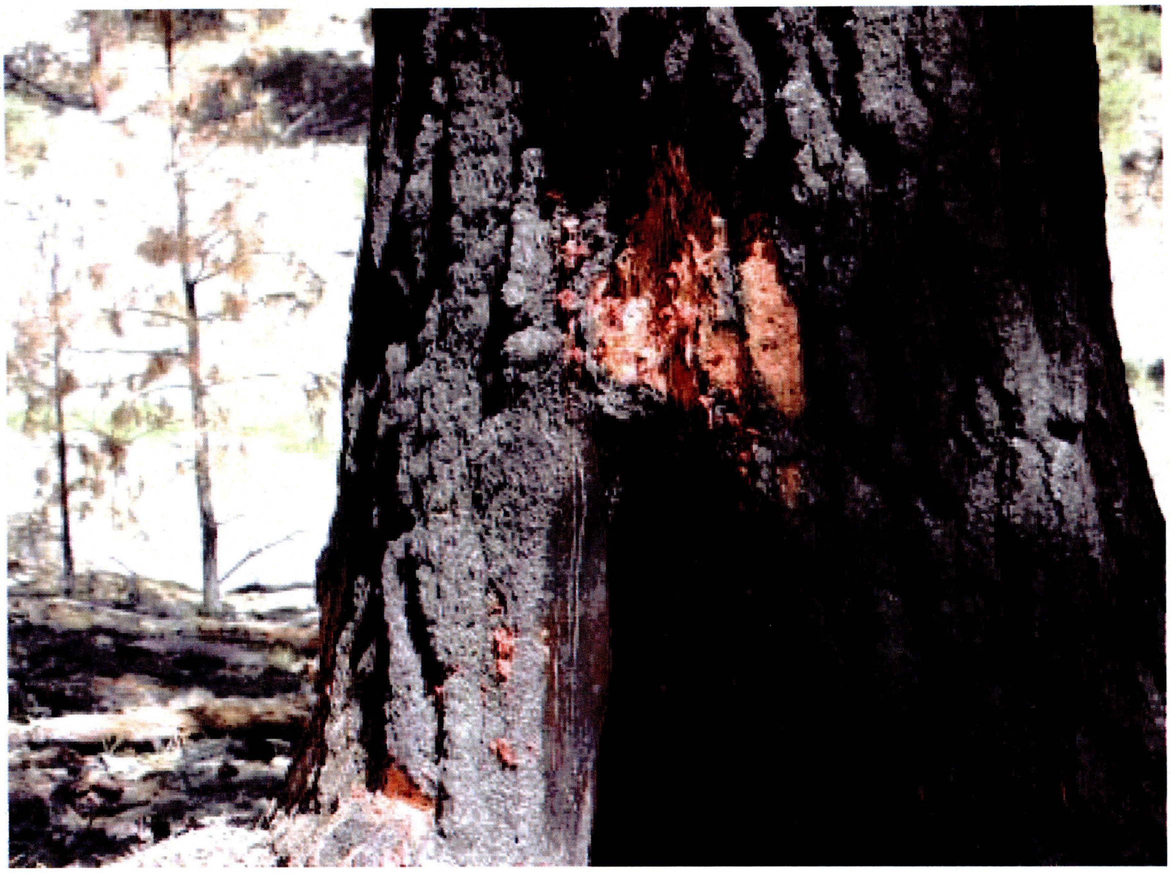


Figure 5. Red turpentine beetles attacking around partially burned out area on old-growth ponderosa pine on Blackrock Natural Fuels Reduction Project, Emigrant Creek Ranger District (photo by D. W. Scott, August 29, 2001).

Although there will be some delayed tree mortality to the old-growth pines on this burn, the prospects are probably low to moderate, given the varying amounts of cambium damage observed on roots and root crowns, and the overall level of beetle populations within a few miles of this part of the unit.

Fading trees were noted in only a few places in this portion of the unit. In one case I observed a 36-in. ponderosa pine that was beginning to fade. It had poor compliment of needles, and following the underburn there was mineral soil exposure on about 50% of the area around the bole. I did not see any evidence of beetle attacks possibly related to fire injury; but I would not rule out the possibility of infestation by woodborers since they leave no visible sign of attack on the exterior of the tree until they complete development and emerge. This tree was clearly in a state of decline, and may have even begun to die prior to the underburn. This tree will likely be red next summer; and western beetles that could attack the tree next summer may hasten its death. Within this location, I observed several other large pines that had cambium damage similar to the fading tree, but differing in that they were not fading, and also in the fact that they had turpentine beetles present.

My impression was that in many places on Unit A-3 the soil and duff moisture conditions may have been almost too low at the time of ignition to avoid consuming much of the duff to mineral soil, resulting in excessive heating of soil around the larger trees. Excessive heat may have reached critical tissues in roots and around the root crowns of many of these trees causing injuries that will hasten their death in the future; and only time will tell. Therefore, it would be prudent to monitor survival of some of these trees over the next 3 or 4 years.

The final stop we made in the Blackrock Natural Fuels Reduction project area was in the northern end of unit A-3. These stands also contained a scattered component of large old-growth ponderosa pines. This area was part of the Calamity Timber Sale that occurred from about the early to mid 1990's. I observed that the large-diameter trees located on the north aspects contained varying levels of dead cambium on roots and root crown; however, many trees also had a good proportion of live cambium tissue present, as well. I would anticipate that there will be some level of delayed tree mortality in this area over the next 2 or 3 years, but I don't believe it will be quite as high as what may occur on the Joaquin Underburn. The ground in this portion of the unit seemed to have an abundance of both surface rock and subsurface partially exposed boulders which may indicate the possibility of lower soil moisture retention that could help contribute to drought-stress conditions in future years causing additional mortality in the fire-injured, large tree component. While soils tested hydrophobic around these big trees with varying amounts of exposed mineral soil, this condition will in part be ameliorated during freeze-thaw cycles in future years.

Holmes Canyon Prescribed Fire (Unit # 3)

The Holmes Canyon Prescribed Fire is located on a portion of the former Snow Mountain Ranger District that is now part of Emigrant Creek RD. The first area we visited in the Holmes Canyon Prescribed Fire was located adjacent to Forest Road 4115. The underburn on this unit occurred on 300 acres in late May of 2001 and was ignited by ATV with drip-torch and hand lighting with drip-torch. At the time of ignition, 1000-hour fuel moisture conditions were at about 17% moisture content according to district fire personnel. There were a total of three units burned in this project. One unit was burned each year over three consecutive years beginning in 1999. This area, being easily accessible from Forest Road 4115, has had a lot of woodcutting in the past, and relatively few snags and little down woody materials are now present in many of the stands.

Most of the ponderosa pines in this unit are large trees averaging over 200 years of age. This area is part of a designated old-growth unit (fig. 6). District silviculture personnel observed that pine needle sheathminer, *Zelleria haimbachi*, were present in this unit in 2000, and in past years too, but that insect was not causing a significant amount of damage to pines. Other than bark beetles commonly associated with fire such as red turpentine beetle, pine engravers, and woodborers, I saw no evidence of other insect infestations of significance over most of this portion of the unit.

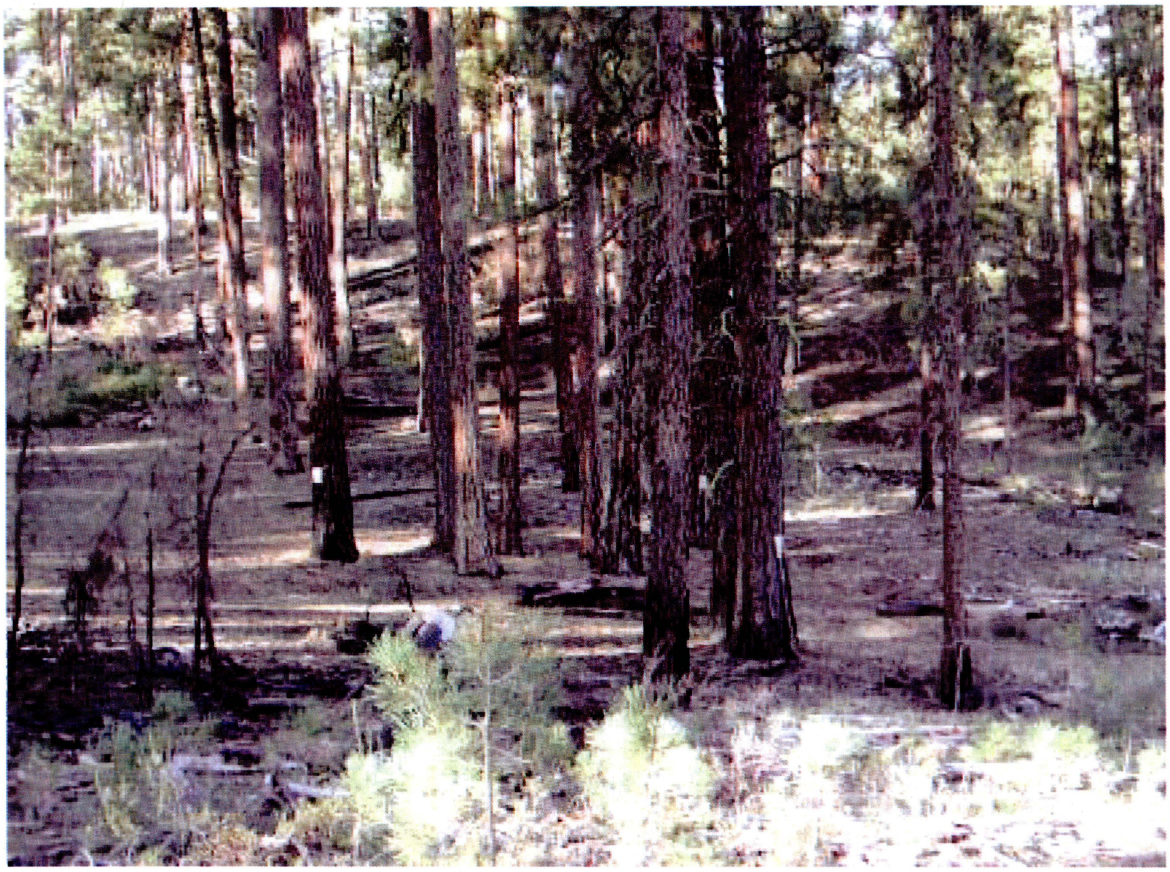


Figure 6. Portion of a dedicated old-growth ponderosa pine stand located within the Holms Canyon Prescribed Fire, Emigrant Creek Ranger District (photo by D. W. Scott, August 30, 2001).

The underburn resulted in a mosaic burn pattern through this unit, with varying burn intensities distributed over the landscape. In certain places, we observed where fire had not completely consumed the duff around the boles of trees, nor the ground cover vegetation (fig. 7). But, we noted that where duff had been consumed to bare mineral soil in a few places, the tree roots contained small strips of dead cambium. For the most part, we did not see much dead cambium on these trees, and no related insect activity. The places where we did find dead cambium were in the more exposed portions of root or root crown at the bases of the trees where 100 percent duff consumption occurred. Yet, even in several of these situations the bark still maintained some structural integrity, and was still in place, even near the base of the tree at the ground line (i.e., there was no evidence of bark sloughing and severe charring at the root collar). This indicated to me that the fire was probably not intense enough to burn for very long up against the trunk of these trees, possibly because the duff was quite moist, and difficult to combust completely. We also noted that the litter and duff were not very deep on some of these trees prior to the burn. Duff appeared to be around 3 inches deep, and varying up to 5 or 6 inches on the uphill side of trees. This site also appeared to be a somewhat moister site than the Joaquin and Blackrock sites.

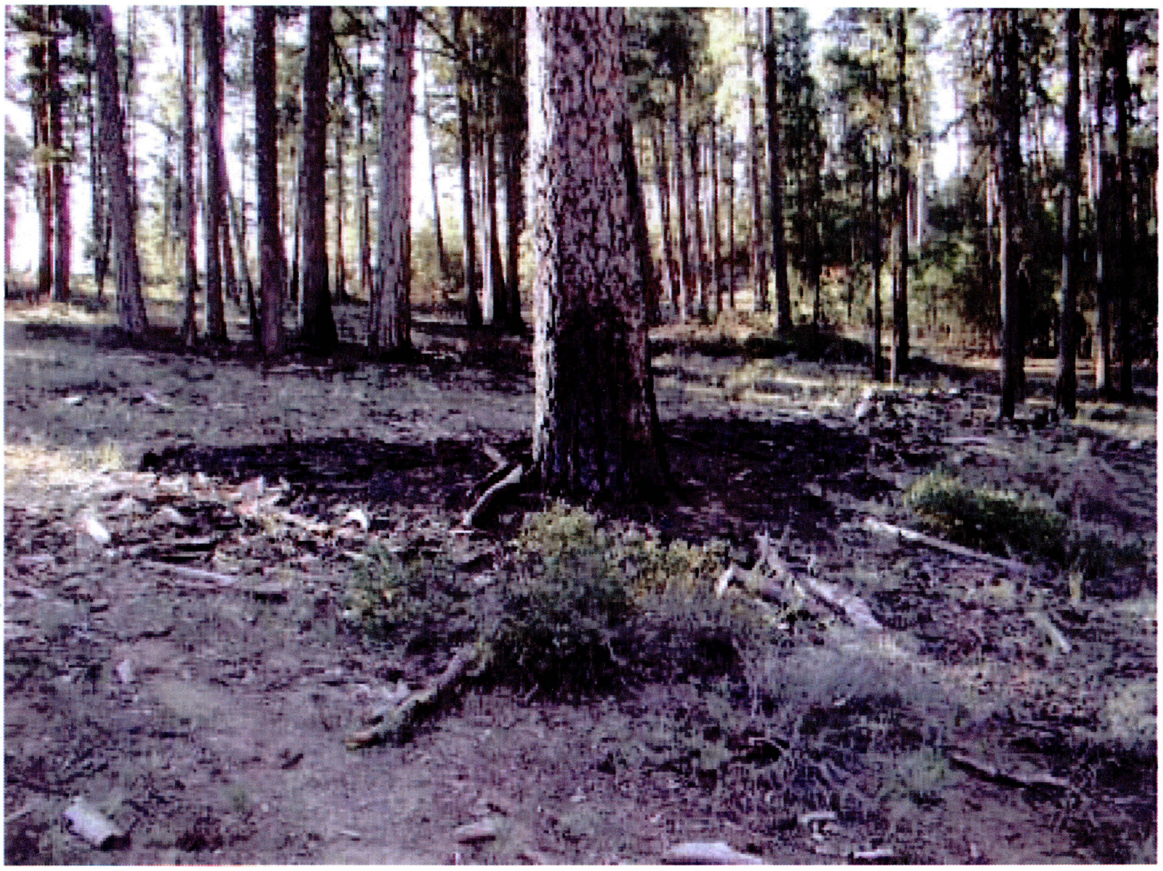


Figure 7. The duff layer around large-diameter ponderosa pines on some portions of the Holms Canyon Prescribed Fire, Emigrant Creek Ranger District, was not entirely consumed, nor was much of the ground cover vegetation (photo by D. W. Scott, August 30, 2001).

However, the fire seemed to burn much hotter in certain other places on the unit. Where that occurred, we often found red turpentine beetles invading the injured base of the tree. In one old-growth pine the fire had burned deeply into an old fire scar at the base of the tree, and most recent fire injured areas around the old fire scar were attracting red turpentine beetles. We observed at least two other earlier fire events at the site of this fire scar, indicating that frequent occurrence of natural fire events were probably common in these stands in the past. The fire had also killed much of the Ceanothus spp. and bitterbrush on this site, but did not completely consume all the needle litter or surface fuels in this portion of the unit.

At another nearby location, where the fire had burned with higher intensity around a group of three old-growth pines, we noted severe injuries to these trees, and portions of their boles had been consumed leaving deeply charred xylem and considerable dead bole and root cambium (fig. 8). The severe injuries to these trees were related to combustion of heavy fuels that had been lying between the trees. The long residence burning of these fuels generated intense heat that caused the injuries to the adjacent trees. Dead cambium was present on roots and around the bases of a couple of these trees, and attacks by red turpentine beetles were abundant on all three trees (fig. 9). Wherever large woody fuels are close to the boles of standing trees, dead cambium will nearly always be present due to long duration radiant heating of the boles during combustion of the nearby fuels.

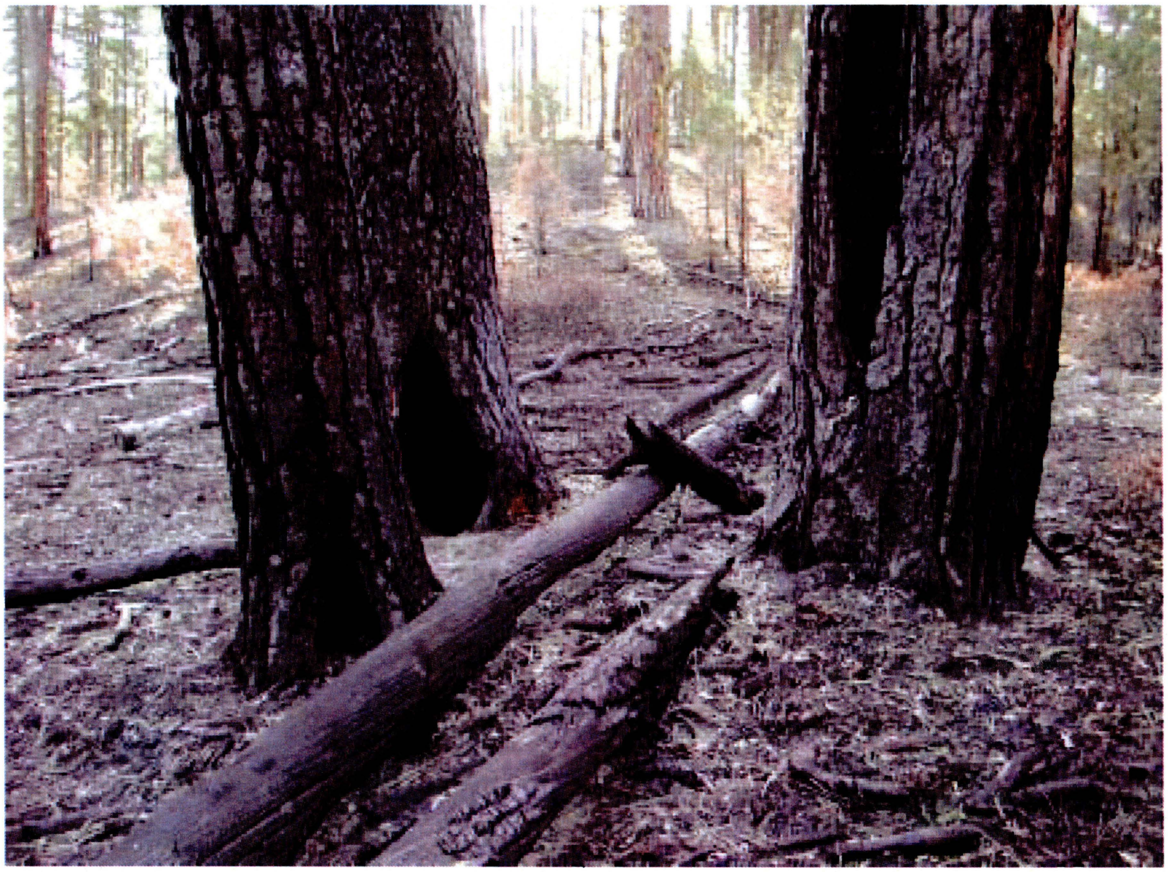


Figure 8. Severe fire injuries to a group of three old-growth ponderosa pines located on the Holms Canyon Prescribed Fire, Emigrant Creek Ranger District. Note distribution of large woody fuels (photo by D. W. Scott, August 30, 2001).

There is, of course, high probability of tree mortality in these situations because of the amount of dead cambium present and associated prolonged stress to these trees during the post-fire recovery period. Bark beetles and woodborers will be attracted to these trees and most likely kill them within the next 2 or 3 years.

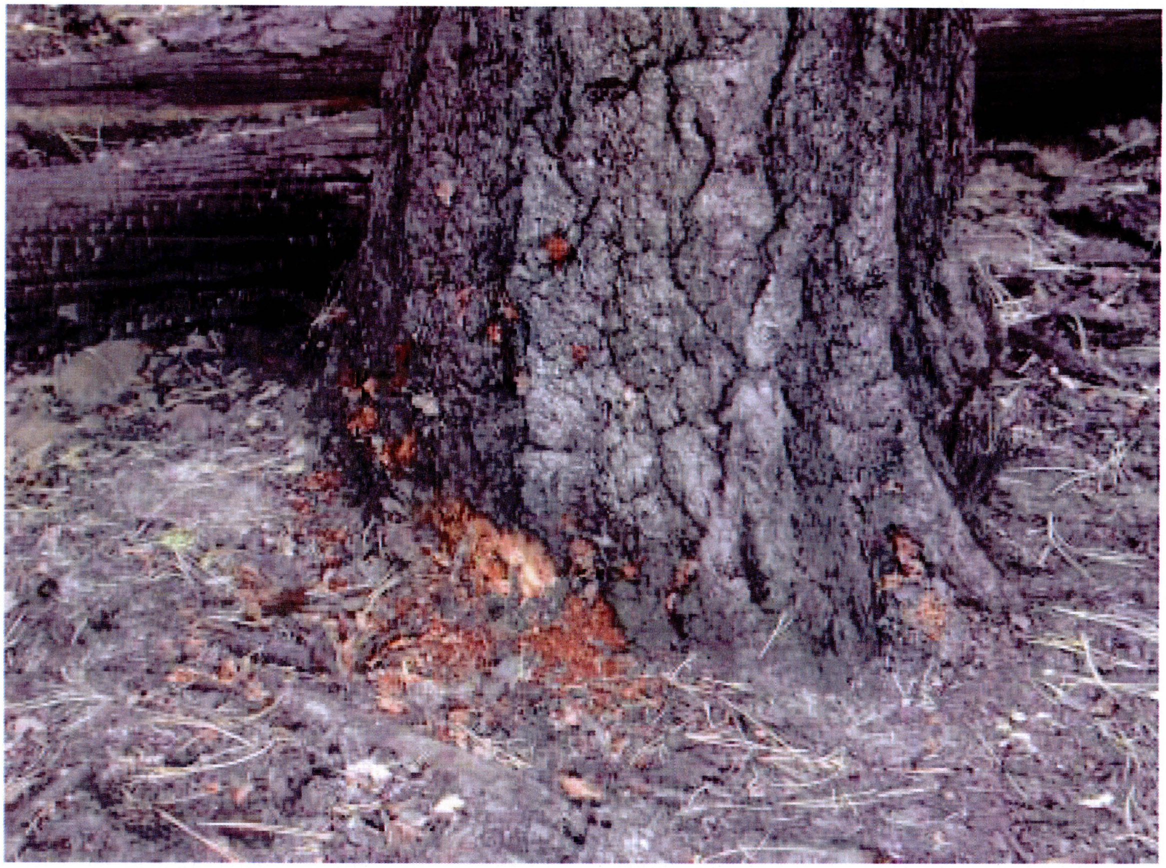


Figure 9. Red turpentine beetle attacks at base of severely fire-injured old-growth ponderosa pine on Holmes Canyon Prescribed Fire, Emigrant Creek RD (photo by D. W. Scott, August 30, 2001).

We also noted that in areas where high heat was generated combustion gases created a "chimney" effect that caused scorching of crowns and injuries to portions higher up on the bole. Woodborers and western pine beetles appeared to have attacked the boles of a number of trees in this condition (fig. 10 and 11). Smaller diameter trees adjacent to these had been heavily attacked by pine engraver beetles (fig. 12). There will inevitably be considerable tree losses—both large and small trees—in this location, and in other similar areas where the fire burned too hot.

Western pine beetles will most likely attack some of the larger trees in the future but I would not expect the number of large-tree losses on this unit to equal that in future years on Joaquin; still, I would venture a guess that losses could reach as high as 10-15% of these large trees over the next 2 or 3 years. This unit, like the Joaquin Underburn, would be an ideal area to set up some long-term monitoring plots to follow the course of tree survival over the next several years.

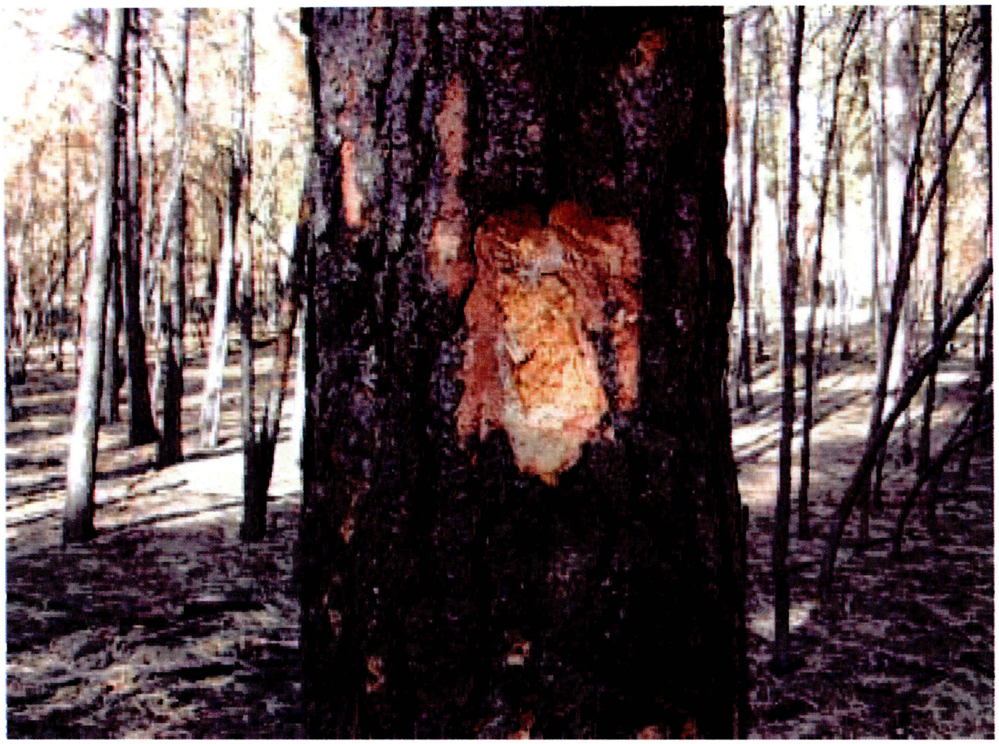


Figure 10. Larval galleries of western pine beetle under bark of fire-injured old-growth ponderosa pine on the Holmes Canyon Prescribed Fire, Emigrant Creek Ranger District (photo by D. W. Scott, August 30, 2001).

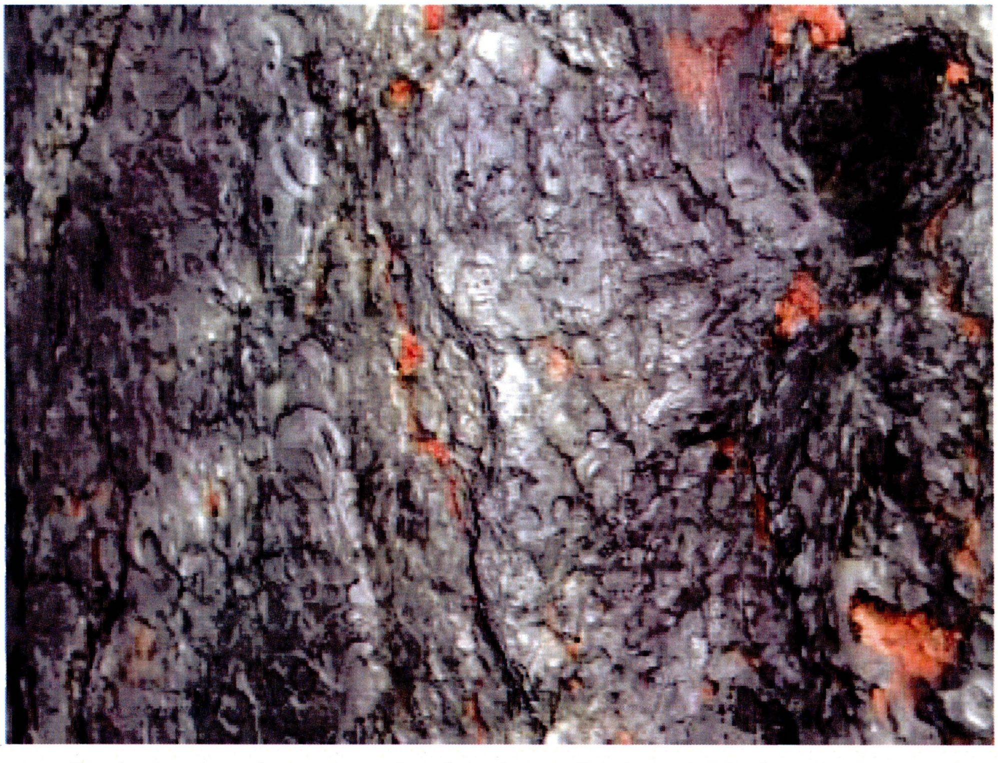


Figure 11. Pitch masses of western pine beetle on fire-injured bole of old-growth ponderosa pine on the Holmes Canyon Prescribed Fire, Emigrant Creek Ranger District (photo by D. W. Scott, August 30, 2001).

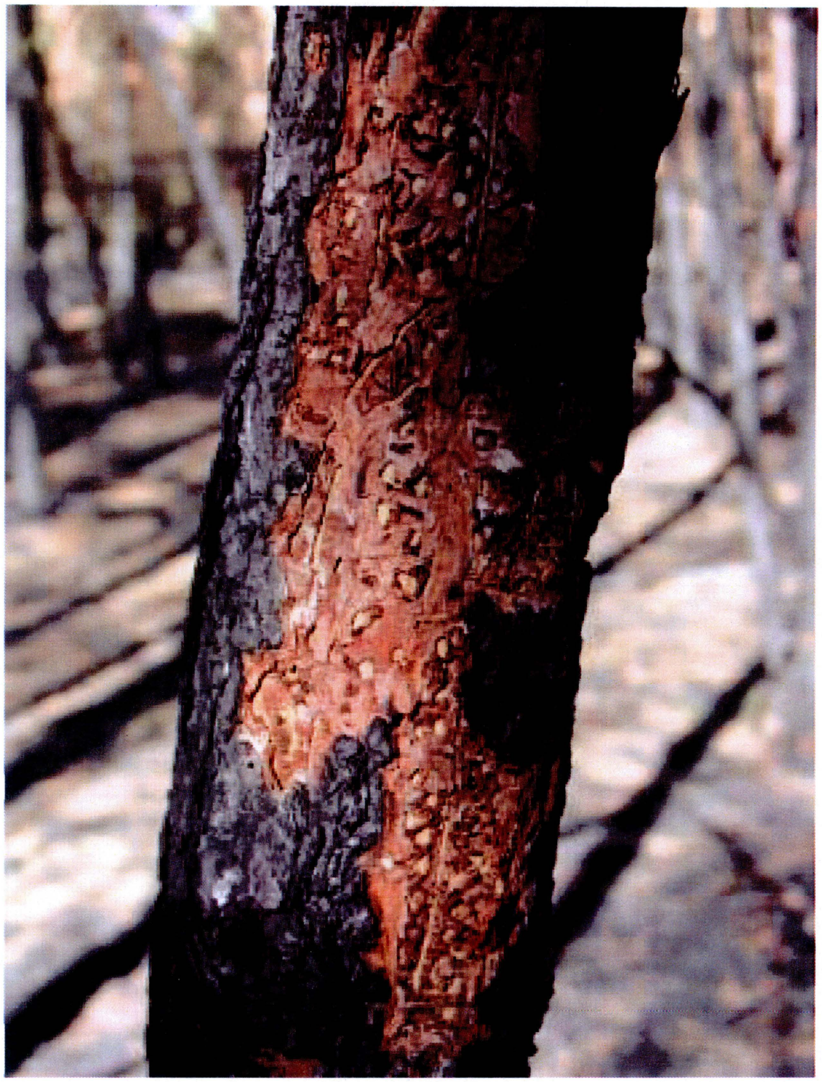


Figure 12. Pine engraver beetle galleries on ponderosa pine on the Holmes Canyon Prescribed Fire, Emigrant Creek Ranger District (photo by D. W. Scott, August 30, 2001).

Holmes Canyon Prescribed Fire (Unit # 2)

The next unit we visited was the Holmes Canyon Unit #2. This unit is comprised of about 150 acres also located along Forest Road 4115. Unit #2 was burned during the first week of May 2000. It was ignited from the ground in the same manner as Unit #3 (ATV and hand lighting). However, this area appeared to have received a lighter burn than Unit#3.

According to district fire personnel the fuel moisture level at time of ignition was not quite as dry as during the 2001 burn, even though this site is slightly dryer than Unit#3. The soil makeup on this unit may also be somewhat different than Unit #3, too. This stand is overstocked with an average tree size smaller than trees on Unit#3, and appeared to contain fewer residual old-growth ponderosa pines as well.

As we walked through this unit, in several places we observed the occurrence of 100 percent duff consumption exposing mineral soil around trees. In most cases we did not find dead cambium beneath the phloem, except for very slight cambial mortality in a few places on these trees. I did not observe any cases of bark beetles nor tree mortality occurring in this Unit.

The sites we reviewed did not appear to have the amount of brush and needle litter, nor depth of accumulated duff that seemed to be present on Unit #3. Overall, it was my impression that the burn on this unit was accomplished under near optimal conditions, and the project resulted in little damage. I would anticipate little delayed tree mortality as a result of the fire injuries to most of the trees in this unit that I observed.

We did find one location where western pine beetles had attacked one small diameter (6 or 7 inches dbh) tree that was in a pocket of several fire-injured pines of about the same size. However, because of the relatively light damage to most other trees in this unit, I would not expect that these beetles will spread beyond this group of trees during the next year or two.

There appeared to be some level of blackstain infection to pines in this stand, and we observed killing of a few trees, possibly related to attacks by woodborers rather than bark beetles. Given that this is a somewhat different mode of action of tree killing of blackstain-infected trees, it bears watching. I suspect that stand conditions in this unit have been stable for a long time (very little disturbance), and rates of tree mortality in the past associated with root disease or insects were probably limited to only an occasional infected tree. Any insect infestations in the near future will probably not be much different than they have been in the past since fire injuries to pines after this underburn appeared to be nominal.

Aside from the few infected trees that are occasionally killed by woodborers or bark beetles in this unit, I would not expect to see significant beetle-caused tree mortality until such time as this stand grew into a greater stand density condition that placed the stand at higher risk to attack by bark beetles.

Holmes Canyon Prescribed Fire (Unit # 1)

This unit was the first Holmes Canyon Prescribed Fire unit to be burned back in 1998 or 1999, during the spring of the year. The unit is located adjacent to the Forest Road 41.

Unit #1 appeared to have burned even lighter than Unit #2. The stand we reviewed had the appearance of being a somewhat declining old-growth ponderosa pine stand with characteristic openings created by tree mortality from various causes. The canopy openings had regenerated with ponderosa pine seedlings several years ago. Now these areas are occupied with sapling-size trees in an overstocked condition. In a few places on this unit, some of the large pines had blown down during windstorms, but any beetle infestations associated with this blow-down, or the adjacent standing green trees, appeared to be light. We found only one 18-22-inch tree than had been attacked by western pine beetles and woodborers 2 or 3 years ago.

Flamelengths during the underburn had caused 4-5 feet of scorching on some of the sapling-size trees, but there didn't appear to be any tree mortality as a result. The boles of larger trees were scorched to less than 1 foot, and duff was not completely consumed around these trees. Unburned duff areas around larger trees appeared to be only 3 or 4 inches in depth. The soil moisture on this unit may have been slightly higher than on the other Holmes Canyon units given the presence of vegetation (prince's pine and pinegrass) that are often found in mid- to high elevation habitats that may be cool and moist, although pinegrass is also common on warm, dry sites, as well (Johnson 1993).

While this unit probably could have benefited from a hotter burn, it will probably be necessary to do some manual thinning and jackpot piling and burning before a hotter underburn can be safely accomplished in the future.

Discussion

In most comparisons I have made of spring verses fall burning in the warm-dry ponderosa pine types, I have observed generally less injury to bole or root crown cambium of the large trees exposed to spring burning than those experiencing fall burns. Moreover, initial observations suggest that "delayed" tree mortality of the large trees results largely from bark and woodboring beetle attacks in subsequent years; generally, this is also higher in fall burns than in spring burns. I believe this is due to greater heat injury that occurs to root systems during the combustion of deep accumulations of relatively dry duff during fall burning.

Duff reduction is one of the objectives included in most activity fuels and natural fuels prescribed fire treatment programs. However, there appear to be stark differences in post-fire effects on large, mature trees when underburning to achieve duff reductions during a spring burn verses a fall burn. In both cases, complete consumption of duff may result in exposure of mineral soil, though this is more common in fall burns than in spring burns. Observations from burns that we have reported on elsewhere suggest that fall burning is more damaging to the larger-diameter mature trees that have deep accumulations of duff, compared to similar stand conditions when burned in the spring. In the former case, duff is often completely consumed to expose mineral soil, whereas duff is not always fully consumed in the latter case due to higher duff moisture content in the spring of the year. These observations seem to be in agreement with Kaufmann and Covington (2001) who suggest that in the case of their study sites in Grand Canyon National Park, the post-burn old-growth pine mortality rate they observed in a spring burn was possibly lower because higher forest floor and soil moisture levels reduced basal damage to those "presettlement" ponderosa pines that were located in the burn unit.

Our monitoring efforts to follow this situation is an on-going process, but the trend toward higher mortality rates of mature trees from late-season burning in the Blue Mountains does seem to be rather consistent on the prescribed fires observed to date.

This conclusion appears to be contrary to what one would expect given the sensitive condition of tree roots and buds at the beginning of the growing season, and therefore greater predisposition to injury from spring exposure to fire. Moreover, it also seems contradictory to what others have found (c.f. Swezy and Agee 1991). However, the study conduced by Swezy and Agee (1991) was done on heavily pumiced soils that may respond quite differently upon exposure to surface fire during different burn seasons than with pines growing in the deep "Mazama" ash soils in the Blue Mountains. Conversely, Swezy and Agee (1991) have suggested that even though root sensitivity may be highest in the early season, if burning occurs soon after snowmelt the wet duff may inhibit combustion of the lower forest floor and limit root mortality.

Indeed, I believe the effect of differences in duff moisture at the time of ignition on heat generated in combustion, and degree of consumption of the duff layer, may account for differential root damage and the delayed mortality differences we observe in old-growth ponderosa pines between spring and fall underburns. The differences in duff consumption in spring verses fall burns depends upon the moisture profile of the duff as well as the amount and duration of heat supplied from surface fuels. Duff is dried out by heat supplied by surface fuels. Smoldering duff will consume only the amount of duff to the depth that was dried by the surface fuel heat input, and then combustion will go out. For duff to be consumed completely to bare mineral soil there must be enough heat input from surface fuels to dry the duff all the way to the soil surface.

Wet or moist duff dries slowly, and hence burns cooler than dry duff. Moreover wet soils are cooler and remain cooler during burning because heat energy is used to evaporate water (i.e. at the rate of 540 cal/g) and soil has a high heat capacity, therefore both adsorbing more heat energy and also distributing heat better through the soil rather than concentrating the heat at any one location, such as right around heat-sensitive roots. Conversely, dry soils will heat faster and concentrate the effects near the surface.

Fuel moisture content is of elemental importance to the process of ignition and combustion of fuels. Hawley and Stickel (1948), for example, state that when the moisture content of fuels is high, a great deal of heat is used in evaporating the water, and that must be accomplished before the material will ignite. If there is not enough heat remaining to keep the temperature above the kindling point, the fire is extinguished.

In our area, even the first rains in the fall may not be enough to moderate the dry conditions of fuels to alter the rate of combustion of duff to much extent. Oftentimes, the duff is still dry enough during the time of the fall burn that evaporation of water is easily accomplished, and kindling is maintained until complete consumption of the duff has occurred.

Burning conditions in the fall of the year can vary considerably, and we have observed some fall underburns that were so light the area looked like it had been burned in the spring. While moisture content of the fuels is certainly important in helping determine the intensity of the fire and rate of consumption of fuels, other factors that can influence the amount of damage that root systems sustain in a fall underburn may be involved, as well. In their experience with prescribed burning in the fall in southwestern U. S. ponderosa pine stands, Sackett and Haase (1998) noted that fires under old-growth pines were often not spectacular with the litter layer and uppermost part of the fermentation layer being consumed in the flaming fire front, while most of the remaining forest floor (lower duff fermentation and humus layers) were consumed as glowing and smoldering combustion for sometimes up to 72 hours. They observed that in most cases, this long duration of glowing and smoldering combustion allowed and ash layer to form from the top down, thus creating an insulating cover (see Sackett 1988) that prevents much of the heat from escaping, causing it to penetrate the soil. Moreover, they noted that long residence time burning and glowing and smoldering combustion can result in either temperature exceeding 140°F, which causes immediate cambium and root death, or lower temperatures for longer duration that can also kill plant tissues. The biological impact of these heat exposure regimes to the unexposed root structures of large, mature or overmature ponderosa pines can be profound, and the nature or extent of the exposure may ultimately influence their survival.

Lethal and sublethal temperature may be conducted for some distance through the soil when fuel loads are high under mature ponderosa pine stands. For example, on sites with preburn fuel loads ranging from 32 to 86 tons per acre, Sackett and Haase (1998) recorded soil temperatures in 88% of measurement sites (22 out of 25 sites) at 140°F at a location of 2 inches below the soil surface. In 21 of the 25 sites they measured temperatures exceeding 100 °F (averaging 138 °F) at 8 inches below the soil surface. They found that even at 12 inches below the soil surface temperatures exceeded 115 °F. Long duration exposures to even these lower temperatures will kill portions of root systems, thereby weakening the trees by creating drought-stress-like conditions within affected trees. Given these facts, it is apparent why some tree mortality is often delayed in large-diameter old-growth ponderosa pines as we have observed, as well as observed in various other research studies, such as those by Sackett and Haase (1998)

Considering the differences in delayed tree mortality we observe between spring- and fall-conducted underburns, I have formulated a working hypothesize that assumes, based on the foregoing, that soil and duff conditions, being considerably moister after snowmelt in the spring, require more of the heat energy from a prescribed fire conducted at that time of the year to evaporate water, and thus will burn cooler causing less damage to root cambium of the large trees with deep duff accumulation, than when similar stands—but containing drier duff—are underburned in the fall. This suggests, then, that in general there may be less delayed large tree mortality in spring burns than in fall burns, as monitoring has thus far shown.

However, the Joaquin Underburn may be the exception to this, based upon the amount of large-tree root damage I saw during my visit last August. I surmise that the higher level of cambium injury we observed to the old-growth trees in this unit perhaps is due to drier duff and soil conditions at time of ignition than has occurred on numerous other springtime burns observed on the Malheur NF. There were no measurements taken, or estimates made of duff or soil moisture content in the Joaquin Underburn prior to ignition, but I suspect those conditions were quite a bit drier than normal springtime owing to the droughty conditions leading into last winter and the abnormally low moisture content of the snowpack over the winter of 2000-2001 (based on Natural Resource Conservation Service reports). The district fire personnel observed that fuel moisture conditions changed rapidly in this area in the days prior to ignition of the burn, and the 1000-hour fuel moisture conditions just prior to ignition were at 10 percent--some of the lowest fuel moisture levels at which the district has conducted spring underburning. We also know that the Palmer Drought Index indicates that the area was experiencing drought conditions based on data from local RAWS stations. Hence, given the droughty conditions, the low 1000-hour fuel moisture levels, and presumably low duff and soil moisture content at the time of the Joaquin Underburn, this burn may have been conducted under conditions similar to fall burn conditions, rather than typical springtime burn conditions, and this probably accounts for the greater injury to root and root collar cambium on larger trees than is normally expected or observed in a springtime burn.

Given the complexity of factors involved in developing an underburn prescription, what factors can we alter to positively influence survival of trees in the years following underburning? To answer that, it may useful to briefly review some of the literature on fire effects to determine the specific factors influencing injury to root and bole cambium in order to determine which factors we might have some control over during development of prescription and execution of a prescribed fire.

The report by Scott and others (1996) contains a good review of literature discussing some of the important factors addressing fire effects on conifers and the factors and conditions influencing post-fire survival of trees. Modifying some of these conditions in the field prior to ignition, inasmuch as it is within our control to do so, may help to minimize injuries to trees and the probability for tree mortality from fire or insects that often occurs within the first 3 or 4 years after the fire. Notwithstanding the contribution of other factors that influence cambial and root damage, in the most simplistic sense, the injuries to cambium at the root crown and subtending roots are generally the result of consumption of duff and large woody material behind the flaming front of the fire (Reinhardt and others 2001).

However, at a finer scale of resolution it is the duff component characteristics that are important determinants of rate and amount of duff consumption during a fire, and amount and duration of heating that reaches critical root zones. Hence the various factors that seem to have greatest influence on root cambial damage in large ponderosa pines appear to be those in which Frandsen (1987) and various others have determined as being important in controlling duff consumption: duff moisture content, inorganic content of the duff (from mineral soil mixed with the duff), and the concentration of organic mass per unit volume (organic bulk density).

The presence and condition of these factors in duff has great importance in controlling and limiting the smoldering combustion of duff, and therefore the potential injury to heat-sensitive cambium of the roots and at the root collar-region. The influence these factors have on duff combustion can be briefly summarized from the work of Frandsen (1987), Wein (1983), and De Vries (1963), as follows.

Mosture Content:	As mentioned previously, the large heat of vaporization of water in duff provides an effective heat sink to inhibit burning (Frandsen 1987). Studies on several different conifer species suggest that duff ceases to burn when it is within the range of 100 – 150% moisture content (Frandsen 1987). Thus, high moisture content is recognized as an important factor in limiting smoldering combustion of duff.
Inorganic Content:	"The inorganic content occupies space within the void volume that must be heated to the same temperature as its surroundings but does not in turn produce heat" (Frandsen 1987). **Inorganic content of duff** is a factor that contributes to the thermal conductivity of duff (De Vries 1963, cited in Frandsen 1987), increasing heat losses from the combustion zone, and absorbing heat to yield a net loss to the propagation of smoldering (Frandsen 1987).
Bulk Density:	Wein (1983) found that the combustion rate of duff increased with decreasing total bulk densities (cited in Frandsen 1987). Moreover, Frandsen (1987) suggests that densely packed or deep duff may reduce the flow of air to the combustion interface. He speculates that with increasing bulk density, at some point there may be a decrease in the rate of heat release, through a decreased supply of oxygen.

From a practical standpoint, it is not feasible to artificially alter the moisture content, inorganic content, or organic bulk density of the duff prior to ignition. However, it is helpful to understand how these variables act to inhibit smoldering combustion and further aid duff in acting as a barrier to the transfer of heat downward to the mineral soil horizons (Frandsen 1987).

Though it cannot be easily manipulated and controlled, to a large extent moisture content of duff can be monitored, and when moisture content is within an acceptable range to avoid root and root crown cambium damage prescribed burning can proceed. Other than that, it seems the only other options we have to minimize injuries to large trees at the present time are to manage the season of burn and the concentration and distribution of fuels associated with these trees. The next section develops this discussion further to reach some conclusions and provide recommendations to improve the long-term survival of these trees after prescribed burning.

Conclusions and Management Recommendations

Large-diameter, mature or overmature ponderosa pines that have developed deep accumulations of duff for lack of exposure to surface fire for many decades are at the greatest risk of sustaining root and root-crown cambial injury when underburned by prescribed fire. These trees may potentially succumb from either the effects of the fire (first-order fire effects), or from attacks of secondary cambial-feeding insects that are attracted to these large weakened trees in subsequent years (second-order fire effects). These effects may occur regardless of seasonal timing of prescribed underburning, but so far occur less frequently after prescribed fire projects conducted in the springtime, immediately following snowmelt.

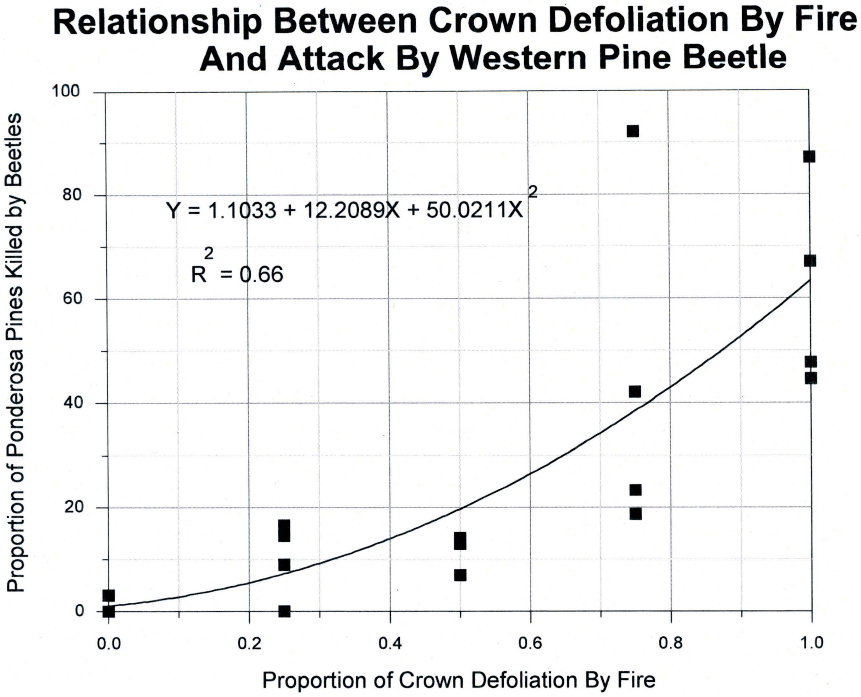
We have observed that as depth of duff increases beneath the tree canopy, especially around individual large-diameter trees, the greater the likelihood of cambium damage to those trees through basal girdling and damage to roots during prescribed fires. These observations concur with Ryan and Frandsen (1991) who found that the probability of cambium mortality of ponderosa pine increased with duff depth and tree diameter during smoldering fires. We are not observing delayed-mortality events related to root damage or basal-girdling nearly as often among younger, second-growth ponderosa pines within the same underburned stands that are either fall or spring ignited because they have considerably less accumulations of duff around the bole and damage to root and bole cambium appears to be less.

In many cases, immediate mortality in the younger second-growth pines appears to be directly related to severe bole cambium damage in smaller diameter trees, or to crown volume loss from fire in nearly any diameter class. Delayed, fire injured tree mortality related to insects occurs in two ways: (1) fire injuries cause a gradual weakening of trees by producing drought-like stress, attracting woodboring beetles and red turpentine beetles that attack, further weakening, and eventually killing the tree; and (2) the same weakening condition may result in a more immediate, multiple tree, or "group-killing" attack by bark beetles when relative beetle populations ("beetle pressure") within adjacent stands are high, resulting in mass attack success. In the latter case, the fire-weakened trees are highly attractive to aggressive bark beetles that attack and kill these trees. As high numbers of beetles arrive and colonize the weakened trees, attraction of the excess numbers of later arriving beetles is terminated by antiaggregation chemicals that are produced by the first wave of beetles that colonized the tree. In this case, the excess beetles undergo a pheromone-mediated "spill-over" phenomenon that results in mass-attacks on one or more adjacent trees.

Based upon my observations mainly from wildfires, woodboring beetles more commonly attack fire-weakened trees than bark beetles. In the case of wildfires, these seem to be the most common group of insects attacking ponderosa pines of all diameter classes after the fire. However, unless they attack with high numbers during a single season, the effects of these beetles seem to be more gradual, particularly in reference to large diameter trees. When populations are relatively low, weakening and eventual killing of fire-injured trees by woodborers may take 2 or 3 seasons.

We have observed that direct, fire-caused tree mortality of second-growth ponderosa pines on prescribed burns frequently occurs when large woody fuels that are in direct contact with the tree, or in close proximity to it, burns with long residence times resulting in killing of a significant area of bole and/or root cambium in the vicinity of the burning woody debris. These injuries may effectively girdle the tree, or kill enough of the root system so that they can no longer support the water replacement needs associated with transpiration by the crown.

Direct mortality of these trees also may result when convection of hot combustion gases supply lethal temperatures to the crown to kill foliage and buds. Bark beetles are frequently attracted to trees when the crown is scorched or partially killed in this manner. To demonstrate how scorched or killed foliage of ponderosa pines can predispose a tree to attack by western pine beetle, depending on the proportional loss of functional crown, we have developed a second-order polynomial relationship (fig. 13) based on data from studies by Miller and Keen (1960). We will eventually be able to analyze our own data set from a variety of studies, many of which are on-going, to refine this relationship and possibly identify others that will be useful in predicting tree mortality rates that can be used in planning for prescribed fires, and in assessing the results following those treatments.



Note: Data from Miller and Keen (1960).

Figure 13. Relationship between crown defoliation by fire and lethal attack of ponderosa pine by western pine beetle.

During rehabilitation planning, and/or follow-up monitoring in both wildfires, and prescribed fires, there is sometimes concern expressed about the risk of developing post-fire bark beetle outbreaks, and indeed we have observed them to occur following certain wildfires. The factors and conditions under which an outbreak may occur vary, and some of these have been identified, at least in part. For example, bark beetle outbreaks have developed as a result of crown defoliation by wildfires (Miller and Keen 1960), but unlike wildfire, most of the time prescribed fires do not normally cause enough damage to crowns to make trees highly susceptible to bark beetles.

The red turpentine beetle is commonly seen attacking ponderosa pines after fires, like we observed in many of the Emigrant Creek prescribed fires during this review. This bark beetle species is normally considered to be a non-economic insect because they rarely kill trees, and only occasionally kill trees under wildfire or prescribed fire, or under other unusual conditions. However, fire-scorched trees have proven to be particularly attractive to these beetles, and such trees have frequently hosted sizable populations (Eaton and Lara 1967). Attacks by other species of bark beetles often precede attacks by red turpentine beetles, but we frequently also see these beetles attacking fire-injured ponderosa pines as the first order of insect succession in these trees, owing to their common flight activity and presence in pine stands throughout most of the spring and summer.

The use of prescribed fire to reduce forest fuel loads is encumbered with the challenge of how to accomplish this and other objectives in a safe, effective manner, and without promoting untoward effects on the environment or the resource. The more of the landscape we treat with prescribed fire, the greater the opportunity we have to study and gain an understanding of the long-term effects of these actions through evaluations, reviews, and monitoring programs. Effectiveness monitoring, for example, may coincidentally lead to a discovery that under certain circumstances even light surface fire may result in a negative impact on a resource component of a stand that was previously unrecognized.

It has been long known that certain insect colonization behavior is closely associated with injuries to trees such as can result from first-order fire effects (e.g., Keen 1928; Miller and Keen 1960). However, it is only in recent times that through follow-up monitoring we are realizing that certain insect/fire associations may be having a greater impact on some stand components than was previously realized.

For sometime now we have been associating at least one negative consequence of certain prescribed fires with the occurrence of fire damaged roots of large ponderosa pines in the Blue Mountains. As we more clearly identify the causes of this undesirable tree mortality, and discover ways to mitigate or prevent it, we will then begin to apply adaptive management to better achieve landscape-scale resource objectives without compromising desirable outcomes or future Forest Plan conditions.

As an agency, we are rapidly moving forward with landscape-scale fuel reduction treatments to protect the forests from future catastrophic fire events. There is broad agreement and support, both within and outside the agency, for actions to reduce fuel loads to make forests more defensible against wildfire, and to protect people and property in the urban interface lands. But as we ratchet up various fuel reduction activities across Regions of the West, it is important to weigh all biological aspects of underburning, especially those about which we have incomplete knowledge, just as we do those aspects that we know well.

Success can be measured not only by the acres of treatment that accomplished stated objectives, but also by the degree to which unintended consequences were avoided. In other words, a guiding principle should be to minimize the risk of creating other problems at the expense of “fixing” the immediate, most visible, or politically important ones. While we may be utilizing the latest technology and science to model and predict fire behavior and fire effects and consequences during the development of landscape prescriptions, these models—as good as they are—may need to be supplemented by a risk assessment analyzing landscape data on the potential for biological consequences such as those just now coming to light. We may find that over time, the model outputs may need to be adjusted in accordance with the needs of each situation, rather than accept *carte blanche* model results and proceed with impunity. Thus, we should be “thinking outside the box,” so that prescriptions or procedures can be modified or changed when conditions point to a potential undesirable outcome, or when new science yields technological improvements that point to an alternate course.

The more I monitor and observe the consequences to the large-tree pine component in forest stands where surface fire is being reintroduced back into an ecosystem from which it has been absent for many decades, the more it becomes clear to me that perhaps we need to begin looking at modifications to some of our practices in conducting prescribed underburning where large pines are involved.

It seems the further removed in time we are from certain recent burn events, the more the delayed mortality of large, mature ponderosa pines becomes apparent. But, so as not to mislead, I need to be clear that not all the large pines are dying within the stands being underburned in the spring or the fall. However, enough of them are to raise concern over these losses. My concern stems not only from the fact that these pines are already in dwindling numbers across the landscape, and the affected trees represent a continuing loss of this important component of the gene pool that should be conserved as much as possible (Wickman 1992), but also from another biological point of reference: Once these highly attractive trees are infested by bark beetles they are capable of producing enormous broods leading to large infestations.

If enough of these large brood trees are concentrated in an area, they can set in motion an insect outbreak of serious proportions. Potentially, they can have profound impact on the green tree volume in the stands within which they occur. We only need look as recently as the Summit Fire on the Malheur NF of a few years ago to see how quickly such a condition can develop. In the Summit Fire, many of the "fire-survivors" (beginning with the large, old-growth ponderosa pines) were killed in large numbers by an outbreak of the western pine beetle.

Given the likely scenario of unintended loss of more than just a few large ponderosa pines, it might be prudent to reevaluate how current procedures may be affecting biological events 5 or more years beyond the initial year of treatment. It has become clear that we can't always know the full impact of certain actions undertaken on the landscape at the time of the action. In some situations, the consequences take time to develop, and are realized some time out in the future. Based on observations in this review and others, and from published studies, I would like to suggest a few things that might help accomplish prescribed burning in stands containing large, mature and overmature ponderosa pines, with an aim toward lowering the overall incidence of delayed tree mortality from insects and fire injuries, in post-fire years.

Fall Burning

Presettlement ponderosa pine restoration studies conducted recently in the northern Arizona at the Gus Pearson Natural Area (see Feeney and others 1998) have demonstrated that prescribed burning in the fall can be safely done with no apparent detrimental effects on "presettlement" ponderosa pines (those that established before 1876). However, in those studies the authors greatly reduced fuel loads before burning by thinning the "post-settlement" trees (those that established after 1876) to an average of approximately 140 sq. ft. of residual basal area per acre, manually raking the forest floor litter away from the base of the large residual trees, and then replacing the O_i duff layer (i.e., the slightly decomposed organic matter consisting of 2-4 year litterfall) with approximately 0.3 tons per acre of dried native grass biomass. Although this treatment was done to simulate the fuel conditions present when surface fires burned regularly through these pine stands, before heavy duff accumulation resulted from lack of burning, this level of pre-burn fuels treatment is ordinarily impractical except for on the smallest of areas such as in a campground or other administrative site.

However, if underburning in stands with large ponderosa pines must be done in the fall, I would recommend some level of mechanical or manual fuel reduction treatment be done prior to burning to ensure large tree survival. At the minimum, large woody fuel concentrations should be pulled away from large pines to a distance of roughly half the crown diameter beyond the drip line of those trees, if possible (and if they could be safely burned there without igniting or killing large portions of the crown during combustion), and the duff should be raked away from the bole for a couple of yards or more, or out to the dripline of the crown prior to burning, leaving no more than about an inch or two of residual duff around the base of the tree. It is advisable to wait for perhaps a year after raking duff away from the bole of large pines before burning to give the tree time to recover from the stress of losing fine roots that may have been extended into the duff layer.

Otherwise, lacking some level of pre-treatment of fuels, it is probably not advisable to underburn stands containing large, old pines in the fall of the year. Without this pre-treatment of fuels, one should expect high levels of mortality to the large-diameter pines having deep accumulations of duff, when underburned in the fall. After a cycle or two of underburning following pre-treatment of fuels, the duff and litter layers will have been reduced to levels similar to those of historic stands when low-intensity surface fire underburned during frequent fire-return intervals. At this time, recurring intervals of fall burning beneath these trees may be resumed on the fire-return cycles that historically characterized the fire regime of the area.

Spring Burning

Cooler temperatures and higher fuel moisture conditions (especially duff moisture) of the early spring season underburns in the Blue Mountains seems to be more conducive to higher survival of mature, large-diameter ponderosa pines. However, I have observed that whenever large woody fuels lying against, or in close proximity to, the boles of these large trees are combusted during underburns, lethal temperatures occur that kill bole cambium and, oftentimes, also kill the roots on that side of the tree due to the long residence time of heat generation during the consumption of those fuels. These trees may suffer large fire scars ("catfaces" or deep xylem charring), if they survive, but it is also possible that they will succumb to attack from insects in future years.

Accordingly, I am recommending that some pre-treatment removal or movement of large woody fuel accumulations away from the boles of mature, large-diameter pines be done prior to underburning around them to lessen the probability of damage to bole and root cambium of these trees. A good "rule-of-thumb" is to follow the fall burn recommendation, and move large fuels the same distance away: a distance of roughly half the crown diameter beyond the drip line of the tree, where they could be safely burned without igniting or killing large portions of the crown during combustion. This distance should provide for an adequate reduction in temperature of radiated heat that reaches the boles of trees nearby since radiant flux from a point source decreases in proportion with the square of the distance (Reifsnyder and Lull 1965).

Secondly, long-duration glowing and smoldering combustion of deep duff accumulations directs heat into rooting zones of large trees and is extremely damaging to roots. Indeed, this seems to be a critical factor in determining the long-term survival of these trees. The moisture content of this duff, in part, helps determine the rate of combustion and degree of duff consumption during the burn. The temperatures that roots will be exposed to during combustion of duff will be lower in duff with high moisture content since a large amount of the heat energy (large heat of vaporization) will be used to evaporate water to dry the duff to sustain ignition levels ahead of the glowing front, thereby conducting less heat into the soil rooting zone (see Frandsen 1987).

Hence, I am recommending that spring underburning around mature, large-diameter trees with deep accumulations of duff be done only during periods when this duff moisture level approaches a level that approximates the "moist" moisture conditions as described by the pre-defined fuel moisture levels in Table 5.1 of the Fire and Fuels Extension Model (Beukema and others 2000) for the Forest Vegetation Simulator (FVS) (see Stage 1973; Wykoff and others 1982).

Normally, this will be when duff moisture content is roughly 100 to 125 percent. The "moist" level of the Fire and Fuels Extension Model is set at a default of 125 percent moisture content. Van Wagner (1972) found that the duff in eastern Ontario pine forests ceased to burn near 140 percent moisture content. It is not known what the moisture content limit to sustained duff consumption is for ponderosa pine, but it may be similar to what Van Wagner reported for jack pine. Higher duff moisture contents will lead to lower amounts of duff consumed during underburning, but high duff moisture level is necessary to provide a margin of safety to avoid complete combustion of duff in order to protect roots from excessive heating during the combustion process. Accordingly, it is probably best to gradually reduce deep duff accumulations around large trees through a series of spring prescribed burns, perhaps spaced 2 or 3 years apart, than to achieve complete duff reduction at the time of only one fire entry. Once the duff has been removed in this manner, it should be safe to re-treat with prescribed fire on the natural fire-return interval that historically occurred in that particular stand or plant community.

Application of Semiochemicals

It is reasonable to expect that trees injured by wildfire or prescribed fire may have depressed production of carbohydrates. Ryan (1990), for example, found by simulation that as crown volume is lost through crown defoliation by fire, the amount of photosynthate that can be produced by the fire-injured tree is reduced. He suggested that, to some extent, the probable decline in water use by the tree resulting from the loss of functional crown volume through scorching, may be compensated by delaying potential water deficits in the tree until later in the season.

However, it is unclear what overall influence that may have, from a survival standpoint, as the injured tree begins allocating carbohydrate resources to replace injured tissues while limiting production of defensive chemicals during a time when bark beetles are actively seeking out hosts to colonize. The availability of carbon for allocation to physiological processes is already prioritized in a generalized hierarchical manner such that production of tree defensive chemicals are relatively low in this scheme (Waring and Schlesinger 1985). Reduced and delayed production of defensive chemicals in fire-injured trees may result in the tree being relatively vulnerable to hosts of bark and woodboring beetles for several seasons following the injuries from fire.

That being the case, it may be possible to supplement the injured tree's chemical defenses by use of insect antiaggregation semiochemicals to protect trees for a period of time while they are especially vulnerable to bark beetles and woodboring insects.

Amman and Ryan (1994) investigated the possibility of using pheromones to protect heat-injured lodgepole pine from infestation by mountain pine beetle. Verbenone, one of the antiaggregation chemicals produced by female mountain pine beetles and male western pine beetles, as well as derived from other sources, had a pronounced effect on attacking mountain pine beetles. The verbenone treatments resulted in a higher percentage of unsuccessfully attacked trees than in controls, even though more attacks occurred on pheromone treated trees with simulated 70-percent basal girdling from fire. Verbenone, however, is not registered with EPA for managing mountain pine beetles or western pine beetles as it has been for southern pine beetles (*D. frontalis*), so we would probably have to consider use of another compound.

Fortunately, the compound 4AA (4-allylanisole), which is present in oleoresin of various pine species, has been shown to deter primary bark beetle species in ponderosa pine (Hayes and Strom 1994; Hobson 1996), and is registered for protecting pines from western bark beetles by EPA. Because 4AA significantly inhibits attacks of these bark beetles on ponderosa pine, it might be a useful treatment to apply to mature pines after an underburn to help protect them from beetle attacks. It would probably have to be re-applied to these trees each year for up to 4 or 5 years after the burn since delayed attacks and delayed tree mortality can easily occur this long after large trees are injured by fire.

I propose this only as a potential "future" management option; one that should be done under a controlled study or as a demonstration, and not as an operational pest management recommendation per se, since we really do not know whether or not this treatment has potential in protecting trees in this case. This treatment would require development of a study plan, and would require a series of observations and measurements over the course of the study to gather appropriate and reliable data that could be analyzed.

Post-burn Monitoring

In the meantime, it is crucial to an understanding of first- and second-order fire effects associated with season of burn and varying burn conditions, and for the need to address Forest Plan effectiveness monitoring, to maintain a strong effort at monitoring responses of these mature, large-diameter ponderosa pines for several years after a prescribed fire treatment. Hence, I am recommending that as part of all future prescribed fire projects, the district include some level (or modification if already occurring) of post-treatment monitoring of their prescribed fires for a period of 4-5 years after treatment to evaluate efficacy of various pre-treatment actions on the post-treatment survival of mature, large-diameter ponderosa pines.

It would be prudent to monitor current, or recent projects as well, such as those I have reviewed in this report. It is important for the district to monitor the long-term effects of both spring and fall burning on the large tree component since maintaining these trees will be critical to achieving Late and Old Structure management objectives in ponderosa pine communities in the southern Blue Mountains. Annual monitoring of the large tree component will help better understand the potentially adverse effects of burning around trees with deep duff accumulations, and enable the application of Adaptive Management principles to minimize these losses in the future.

As the district undertakes this monitoring it is important to remember that black-stain root disease is present in a number of the stands that have been, or will be, underburned. Mortality from this conifer disease may confound interpretation of tree mortality related to fire or insects that may occur after underburning. Accordingly, it is advisable to conduct a root disease survey to map locations of any black stain in stands scheduled for treatment before they are underburned. I would be happy to discuss this further with the district, or advise the district on developing monitoring guidelines or procedures, and a monitoring plan. Our Service Center Pathologist is also available to assist with issues related to black-stain root disease or other disease problems associated with stands.

Adaptive Management

Clearly, where we must operate within some areas of biological uncertainty it becomes necessary to apply the current state of knowledge within the context of adaptive management. For example, in the foregoing I have proposed several recommendations that, based on personal observations, professional judgment, and the best information currently available in the published literature, provide guidelines to improve post-fire survival of large ponderosa pines where they occur on the landscape. These recommendations are not offered as the final authority on conducting underburning around mature, large-diameter ponderosa pines with deep accumulations of duff, nor do they guarantee tree survival in every case. However, I believe these recommendations will help to lower post-treatment tree losses in the future, while additional studies will gradually increase our understanding of fire effects, and incrementally improve the technology or procedures for underburning so that future prescribed fire activities will increase probability of survival of the large-diameter ponderosa pines in those stands. As new information and improvements in technology emerges, adaptations will need to be made to accommodate these advancements, and these will ultimately lead to better measurements of large-tree survival "success." Many factors influence adaptive management decisions. Additional study and careful observations will be required to evaluate the effectiveness of recommendations when applied under varying conditions of stand and fuel composition, moisture content, weather and microclimate, ignition pattern, and many other factors; and these will help guide certain adaptive management decisions in the future.

Accurate record keeping is essential to track these variables and their influence on post-burn tree survival. The factors influencing the long-term survival of late and old structure ponderosa pine on dry sites in the Blue Mountains after underburning are very complex. Most likely, we will not be able to identify a single solution that will assure survival success in every case, short of taking such extreme and impractical actions as Feeney and others (1998) did on the Gus Pearson Natural Area in Arizona, mentioned earlier. However, research into various aspects of these factors is being carried out on several fronts across the west. Some of the current research that we are involved in may help to elucidate some of the impacts related to season of burn of prescribed fire on post-fire infestation by insects and long-term survival of large-diameter ponderosa pines in eastside dry ponderosa pine communities. This research is on-going and should help to fill in some of the gaps in information related to first- and second-order fire effects on ponderosa pine survival (e.g., Niwa and Scott 2001).

There is one final recommendation I would like to make relating to the need for adaptive management. My recommendation is simply a plea to continue to keep good records of all pre-treatment and pre-ignition conditions so that as post-burn monitoring is carried out there will be good linkage between observed results and the controlling factors documented in the records. With adequate record keeping, appropriate adjustments in practice can then be made based upon this documentation, correlated with observed biological responses.

During the review we discussed one good way to achieve this goal, and that is to maintain a prescription database that not only documents all pertinent pre-burn parameters and conditions, including among others duff moisture content, but also annotates post-burn results and consequences. If these records are maintained for every prescribed fire, they will eventually cover a wide variety of conditions that will be very valuable in helping to establish biological cause and effect relationships, and help point out when adaptive management is needed.

Given the potential variability of spring verses fall burning effects on vegetation under varying conditions, differences in biological responses may not be readily apparent because of delays in physiological processes. Research may be designed to statistically evaluate the variables affecting tree survival during a critical time period under each season that burning takes place, and thereby provide a scientific basis for developing guidelines in prescribing treatments to minimize future losses of large ponderosa pines. But research alone cannot be so encompassing and broadly focused that it analyzes every possible condition that will be encountered in the field. The district, during implementation of operational-scale projects will be in the best position to scrutinize the results and determine situations that need to be changed. In effect, this is a critical part of a "feedback" loop to identify areas of further investigation.

Reviews like this can be very helpful, too. Inviting other sets of eyes to scrutinize results can sometimes help to detect conditions that may have gone unnoticed, or help establish cause and effect relationships. The information accumulated by many through research studies, reviews, monitoring programs, and just plain good record keeping will result in advancements in knowledge and understanding that will give rise to improvements in prescribed fire practices, procedures, and technology. These then become the foundation and means by which adaptive management can be applied in the prescribed fire program for the benefit of the resource.

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